PUTP-94-26

$\xi(2230)$ IS LIKELY TO BE A GLUEBALL [1]

Kuang-Ta Chao

CCAST (World Laboratory), Beijing 100080, P.R.China
and
Department of Physics, Peking University, Beijing 100871, P.R.China

Abstract

On the basis of the recent results of $\xi(2230) \to \pi^+\pi^-$, $p\bar{p}$ and $\xi(2230) \to K^+K^-$, K_SK_S, measured by the BES Collaboration in J/ψ radiative decays, combined with the PS185 experiment of $p\bar{p} \to \xi(2230) \to K\bar{K}$, we argue that because of its very narrow partial decay widths to $\pi\pi$ and $K\bar{K}$ (less than 1 MeV), its large production rate in J/ψ radiative decays, and its flavor-symmetric couplings to $\pi\pi$ and $K\bar{K}$, the $\xi(2230)$ is very likely to be a $J^{PC} = (even)^{++}$ glueball.

[1]Talk presented at the CCAST Workshop on Tau-Charm Factory, Beijing, November 1994

The $\xi(2230)$ particle, a narrow state with a width of about 20 MeV, was first observed by the MARK III Collaboration at SLAC-SPEAR in the radiative decays of J/ψ to K^+K^- and K_SK_S final states[1]. There are many speculations about the nature of $\xi(2230)$. It could be an ordinary $s\bar{s}$ quarkonium state[2], a baryonium state such as $(qs)_{3^*}-(\bar{q}\bar{s})_3$ with q being a u or d quark[3], a $\Lambda\bar{\Lambda}$ bound state[4], an $ss\bar{s}\bar{s}$ state[5], a $\bar{q}qg$ hybrid[6,3], or a glueball[7].

Recently, the BES Collaboration at BEPC (Beijing Electron Positron Collider) has reported new results of the $\xi(2230)$. Two significant decay modes $\xi \to \pi^+\pi^-$ and $\xi \to p\bar{p}$ have been observed in addition to $\xi \to K^+K^-,\ K_SK_S$. The measured mass, width, and branching ratios are as follows[8].

In $J/\psi \to \gamma\xi,\ \xi \to \pi^+\pi^-$:

$$\begin{aligned} &M_\xi = (2235 \pm 4 \pm 6)MeV, \\ &\Gamma_\xi = (19^{+13}_{-11} \pm 12)MeV, \\ &BR(J/\psi \to \gamma\xi) \times BR(\xi \to \pi^+\pi^-) = (5.6^{+1.8}_{-1.6} \pm 1.4) \times 10^{-5}. \end{aligned} \tag{1}$$

In $J/\psi \to \gamma\xi,\ \xi \to p\bar{p}$:

$$\begin{aligned} &M_\xi = (2235 \pm 4 \pm 5)MeV, \\ &\Gamma_\xi = (15^{+12}_{-9} \pm 9)MeV, \\ &BR(J/\psi \to \gamma\xi) \times BR(\xi \to p\bar{p}) = (1.5^{+0.6}_{-0.5} \pm 0.5) \times 10^{-5}. \end{aligned} \tag{2}$$

In $J/\psi \to \gamma\xi,\ \xi \to K^+K^-$:

$$\begin{aligned} &M_\xi = (2230^{+6}_{-7} \pm 12)MeV, \\ &\Gamma_\xi = (20^{+20}_{-15} \pm 12)MeV, \\ &BR(J/\psi \to \gamma\xi) \times BR(\xi \to K^+K^-) = (3.3^{+1.6}_{-1.3} \pm 1.1) \times 10^{-5}. \end{aligned} \tag{3}$$

In $J/\psi \to \gamma\xi,\ \xi \to K_SK_S$:

$$\begin{aligned} &M_\xi = (2232^{+8}_{-7} \pm 15)MeV, \\ &\Gamma_\xi = (20^{+25}_{-16} \pm 10)MeV, \\ &BR(J/\psi \to \gamma\xi) \times BR(\xi \to K_SK_S) = (2.7^{+1.1}_{-0.9} \pm 1.0) \times 10^{-5}. \end{aligned} \tag{4}$$

These results indicate that the $\xi(2230)$ decays are probably flavor symmetric, and its total width is as narrow as about 20 MeV. These features may make $\xi(2230)$ distinguishable from many other states.

The situation will become most clear-cut when combining the BES result with the experiments E789[9] at BNL-AGS, PS170[10] at CERN-LEAR, and PS185[11] at CERN-LEAR aimed at $\xi(2230)$ in the reaction $p\bar{p} \to \xi(2230) \to K\bar{K}$. These experiments find no any significant structure in the $\xi(2230)$ region and only give an upper bound for the following product of branching ratios (see, e.g., refs.[11,12])

$$BR(\xi \to p\bar{p}) \times BR(\xi \to K\bar{K}) < 1.5 \times 10^{-4}, \tag{5}$$

where $J=2,\ \Gamma_\xi=20MeV$ for $\xi(2230)$ are assumed, and where $K\bar{K}$ include all kaon pairs.

Note that $BR(\xi\to p\bar{p})$ measured by BES is only four times smaller than $BR(\xi\to K\bar{K})$. Then combining the BES branching ratios given in (1)-(4) with the PS185 result (5), and taking again $\Gamma_\xi=20MeV$, we find

$$
\begin{aligned}
&BR(\xi\to\pi^+\pi^-)<2.4\times10^{-2}, &&\Gamma(\xi\to\pi^+\pi^-)<480KeV, &(6)\\
&BR(\xi\to p\bar{p})<0.6\times10^{-2}, &&\Gamma(\xi\to p\bar{p})<120KeV, &(7)\\
&BR(\xi\to K^+K^-)<1.4\times10^{-2}, &&\Gamma(\xi\to K^+K^-)<280KeV, &(8)\\
&BR(\xi\to K_SK_S)<1.1\times10^{-2}, &&\Gamma(\xi\to K_SK_S)<220KeV. &(9)
\end{aligned}
$$

In particular, with (1) and (6), we immediately get a rather large branching ratio for $J/\psi\to\gamma\xi(2230)$

$$BR(J/\psi\to\gamma\xi)>2.3\times10^{-3}. \tag{10}$$

With above observed bounds, we can see at least three pronounced features of the ξ.

(1) The partial decay widths of ξ to $\pi^+\pi^-$ and $K\bar{K}$, as shown in (6)-(9), are much smaller than that of any conventional $q\bar{q}$ states, including $(u\bar{u}+d\bar{d})$, and $s\bar{s}$, or their admixtures. It is obvious that for any conventional $q\bar{q}$ meson whose decay is OZI-rule allowed, its total width and partial widths of certain main decay modes must be of order of $10-100MeV$. E.g., for the P-wave $J^{PC}=2^{++}$ mesons, the $f_2(1270)$, which is mainly a $(u\bar{u}+d\bar{d})$ state, has a patial decay width of about $150MeV$ to $\pi\pi$, while the $f_2'(1525)$, which is mainly an $s\bar{s}$ state, has a partial decay width of about $50MeV$ to $K\bar{K}$[12]. For the F-wave mesons, based on some quark model calculation it was argued[2] that if $\xi(2230)$ was a $^3F_2$ or $^3F_4$ $s\bar{s}$ state, its decay to $K\bar{K}$ could be suppressed by the $L=3$ centrifugal barrier and consequently the decay width to $K\bar{K}$ could be lowered to $20-30MeV$, but can not be as small as , say, $500KeV$. On the other hand, the $f_4(2050)$, which is a $(u\bar{u}+d\bar{d})$ dominated $^3F_4$ state, has an observed total width of $200MeV$ and a partial decay width of $30MeV$ to $\pi\pi$ [12]. We see that, with both experimental observations and quark model calculations, all this kind of $q\bar{q}$ states can hardly have a total width of $20MeV$ and, in particular, can not have a partial decay width of, say, $500KeV$ to $\pi\pi$ or $K\bar{K}$, as observed for $\xi(2230)$. Therefore, as the result of observed small partial widths of $\xi(2230)\to\pi\pi,\ K\bar{K}$, we may conclude that the $\xi(2230)$ can not be a conventional $q\bar{q}$ meson.

(2) The $\xi(2230)$ has a large production rate in J/ψ radiative decays which are known as the gluon-rich channels. In fact, according to (10) and the data of J/ψ radiative decays[12], the production rate of $\xi(2230)$ could be only smaller than η_c and $\eta'(958)$, but larger than or as large as $\iota(1440)$, $\theta(1710)$, $f_4(2050)$, and $f_2(1270)$. As discussed above, due to the small partial widths of $\xi\to\pi\pi,\ K\bar{K}$, ξ can hardly be the counterpart of $f_4(2050)$ or $f_2(1270)$, or other $q\bar{q}$ mesons. As for the $q\bar{q}q\bar{q}$ states or $\Lambda\bar{\Lambda}$-like baryon-antibaryon bound states, according to the naive quark pair counting rule, they are usually expected to have smaller production rates than the corresponding $q\bar{q}$

states, since the creation of more quark pairs is needed for $q\bar{q}q\bar{q}$ or baryon-antibaryon bound state production. Most naturally, the rich production of ξ in J/ψ radiative decays will imply that the $\xi(2230)$ is likely to be a glueball or a $q\bar{q}g$ hybrid state, but the former should have an even larger production rate than the latter.

(3) The $\xi(2230)$ decays are probably flavor-symmetric with many decay modes. The closeness of observed decay branching ratios of ξ to $\pi\pi$ and $K\bar{K}$, as shown in (1)-(4), apparently suggests a possible flavor-singlet nature of the ξ, while the smallness of these branching ratios, as shown in (6)-(9), indicates that ξ may have as many as tens decay modes. These two features bear resemblance to the charmonium decays, in particular, to the χ_{c0} and χ_{c2} decays. Both χ_{c0} and χ_{c2} decays may proceed via two steps: first the $c\bar{c}$ pair annihilate into two gluons; and then the two gluons are hadronized into light mesons and baryons. The gluon hadronization is flavor-symmetric and then leads to flavor-symmetric decays. This picture is stronly supported by the χ_{c0} and χ_{c2} decays. E.g., the χ_{c2} is found to have approximately the same decay rate to $\pi^+\pi^-$ as to K^+K^-, and the same decay rate to $\pi^+\pi^-\pi^+\pi^-$ as to $\pi^+\pi^-K^+K^-$[12]. For a glueball, say, a $J^{PC}=2^{++}$ glueball, which is made of two gluons, its decay proceeds via the two-gluon hadronization, which is similar to the second step of the χ_{c2} decay. The difference between the glueball and χ_{c2} in their decays is that the two gluons are hadronized at different energy scales, and consequently in the two cases the branching ratio for a given final state can be different. At the higher energy scale like the χ_{c2} mass, more channels are open and competing, and more particles (pions mainly) are produced with certain averaged momenta to balance the primitive leading particles converted by the gluons, and therefore the decay branching ratio to $\pi^+\pi^-\pi^+\pi^-$ can be larger than to $\pi^+\pi^-$, and that to $p\bar{p}\pi^+\pi^-$ can be larger than $p\bar{p}$, as observed experimentally in the χ_{c2} decays[12]. Despite of this difference between the charmonium and glueball, we believe the observed flavor-symmetric pattern of charmonium decays does lend strong support to the conjecture that the glueball decays should be flavor-symmetric. Another possible feature of the glueball decay is that glueballs probably have more decay modes than conventional $q\bar{q}$ states. A $q\bar{q}$ meson decay occurs when the color flux tube formed by q and $\bar{q}$ is broken at large distances by the creation of new quark pairs (the OZI allowed decays); whereas a glueball decay proceeds via the gluon hadronization. There are more possibilities and combinations for the gluon fragmentation and hadronization than for the quark pair creation in a color flux tube. Therefore, a glueball may have more decay modes than a $q\bar{q}$ meson, and hence have smaller branching ratios to many final states. In these connections, for $\xi(2230)$ the observed flavor-symmetric decays to $\pi\pi$, $K\bar{K}$ and the smallness of these decay branching ratios seem to favor the assignment that the $\xi(2230)$ is a glueball. A $(u\bar{u}+d\bar{d})g$ habrid state may also have comparable strengths to couple to $\pi\pi$ and $K\bar{K}$, but it can be distinguished from a glueball by certain special decay modes, e.g., it can decay to $\omega\phi$ but not to $\phi\phi$. The flavor-symmetric couplings of ξ to $\pi\pi$ and $K\bar{K}$ also disfavor the $q\bar{q}$ states, because flavor mixings should be small for orbitally excited $q\bar{q}$ mesons. E.g., $f_2(1270)$ and $f_2'(1525)$ $(L=1)$ have dominant

decay modes to $\pi\pi$ and $K\bar{K}$ respectively; and the $f_4(2050)$ ($L = 3$) has dominant decay modes to $\omega\omega$, $\pi\pi$, while its branching ratio to $K\bar{K}$ is only 7×10^{-3}[12].

With the three observations made above, we see that the $\xi(2230)$ is very unlikely to be a conventional $q\bar{q}$ meson, less likely to be a four-quark state or a baryon-antibaryon bound state, but very likely to be a $J^{PC} = (even)^{++}$ glueball, though a $q\bar{q}g$ habrid could also be a disfavorable possibility. To draw a more definite conclusion about the nature of $\xi(2230)$, further experimental studies should be done. Following suggestions might be useful.

Searching for more decay modes of $\xi(2230)$. Since the observed $\pi\pi, K\bar{K}$, and $p\bar{p}$ are expected to be, according to (6)-(9), only a small portion of the decay modes of ξ, other decay modes such as $\eta\eta$, $\eta\eta'$, $\eta'\eta'$ and $\pi\pi\pi\pi$, $\pi\pi K\bar{K}$, $\rho\rho$, $K^*\bar{K}^*$, $\phi\phi$ may be important. A systematical test of the flavor symmetric nature in the decays will be crucial for the glueball interpretation of ξ.

Searching for some special decay modes of $\xi(2230)$, e.g., $\omega\phi$ and $\phi\phi$. A glueball can decay to $\phi\phi$ but not $\omega\phi$, whereas a $(u\bar{u} + d\bar{d})g$ habrid may decay to $\omega\phi$ but not $\phi\phi$. Therefore those modes may provide crucial tests for distinguishing between the glueball and the habrid. The $\omega\phi$ mode is also a prediction for the $qs\bar{q}\bar{s}$ state.

Determining the spin-parity of $\xi(2230)$. The spin-parity of ξ could be $0^+, 2^+$ or 4^+. $J^P = 4^+$ will disfavor the glueball and habrid interpretations, because it requires a non-S wave orbital angular momentum between the constituents, and then lead to higher mass and lower production rate in J/ψ radiative decays than $\xi(2230)$. In this connection, it is interesting to note that a comprehensive lattice study of SU(3) glueballs by the UKQCD Collaboration suggests the mass of the 2^{++} glueball be $2270 \pm 100 MeV$[13]. Therefore, if the spin of ξ is experimentally determined to be 2, then the 2^{++} gluball interpretation fo ξ will be even more strongly supported.

Examining the inclusive photon spectrum in the $\xi(2230)$ region in the J/ψ radiative decays. According to (5), the ξ has a large production rate in $J/\psi \to \gamma gg \to \gamma + hadrons$ and therefore should show up as a narrow peak in the inclusive photon spectrum. This will be a test of consistency for the BES[8] and PS185[11] experiments, and is also very important for the understanding of the nature of $\xi(2230)$.

To sum up, we believe that the recent result reported by BES is very encouraging in the idenfication of the puzzling state $\xi(2230)$. With both the BES and PS185 experiments, this particle is found to have striking features that it has very narrow partial decay widths to $\pi\pi$ and $K\bar{K}$, a large production rate in J/ψ radiative decays, and flavor-symmetric couplings to $\pi\pi$ and $K\bar{K}$. These features strongly favor the conclusion that the $\xi(2230)$ is likely to be a $J^{PC} = (even)^{++}$ glueball.

I would like to thank T.Huang, M.H.Ye, and Z.P.Zheng, the organizers of the CCAST Workshop on Tau-Charm Factory, Beijing, November 1994, where this work was presented. I also thank J.Li, J.H.Liu, W.G.Yan, S.Z.Ye, Z.P.Zheng, Y.C.Zhu, and, in particular, S.Jin for many stimulating discussions on the experimental status of $\xi(2230)$. This work was supported in part by the National Natural Science

Foundation of China, and the State Education Commission of China.

References

[1] R. M. Baltrusaitis et al., Phys. Rev. Lett. 56 (1986) 107.

[2] S. Goldfrey, R. Kokoski and N. Isgur, Phys. Lett. B141 (1984) 439.

[3] K. T. Chao, Phys. Rev. Lett. 60 (1988) 2579;
K. T. Chao, Commun. Theor. Phys. 3 (1984) 757.

[4] S. Ono, Phys. Rev. D35 (1987) 944.

[5] S. Pakvasa, M. Suzuki and S. F. Tuan, Phys. Lett. B145 (1984) 135.

[6] M. S. Chanowitz and S. R. Sharpe, Phys. Lett. B132 (1983) 413;
A. Le Yaouanc et al., Z. Phys. C28 (1985) 309.

[7] B. F. L. Ward, Phys. Rev. D31 (1985) 2849.

[8] J. Li, talk given at the 27th International Conference on High Energy Physics, Glasgow, July 21-27, 1994;
S. Jin, talk given at the International Workshop on Hadron Physics at Electron-Positron Colliders, Beijing, October 14-17, 1994.

[9] J. Sculli at al., Phys. Rev. Lett. 58 (1987) 1715.

[10] G. Bardin et al., Phys. Lett. B195 (1987) 292.

[11] P. D. Barnes et al., Phys. Lett. B309 (1993) 469.

[12] Particle Data Group, L. Montanet et al., Phys. Rev. D50 3-I (1994) 1173.

[13] G. S. Bali et al., Phys. Lett. B309 (1993) 378.